

transmission or when terminal has no transmissions on PUSCH. There are multiple use cases for SRS in LTE/LTE-advanced: in LTE, support for channel-aware packet scheduling, support for timing control/power control, support for AMC, and support for MU-MIMO pairing; and, in LTE-advanced, component carrier aggregation, multi-cluster scheduling within one component carrier, support for PMI&RI selection (uplink SU-MIMO), support for downlink CSI estimation at multiple cells exploiting channel reciprocity, and support for collaborative pre-coder/beam selection in UL COMP.

[0020] In LTE/LTE-advanced, SRS is time multiplexed with a demodulation reference signal (DMRS) and uplink data such that one of the SC-FDMA data symbols is replaced by SRS. This results in throughput loss due to additional overhead. Further, sounding capacity is not enough for LTE-advanced features like COMP and SU-MIMO.

[0021] Unused demodulation reference signals (DMRS) resources may be used for sounding. However, such a design may result in an increased inter-cell interference on DMRS. Capacity and overhead may create a challenge for LTE/LTE-advanced based sounding where an SRS signal is time multiplexed with data and DMRS. The inter-cell interference may create a challenge for DMRS based sounding. Pairing of DMRS-based sounding with normal DMRS may create a challenge.

[0022] Regarding the capacity aspect, the use of SRS for closed loop pre-coding and frequency domain packet scheduling (FDPS) requires that each of transmission antennas transmits SRS with a period shorter than channel coherence time and at bandwidth significantly larger than channel coherence bandwidth. This causes significant increase in SRS usage in the event that a considerable share of LTE-A terminals are SU-MIMO UEs or when large portions of UEs are selected for COMP reception (in that case, orthogonal SRS multiplexing is extended over multiple cells). On other hand, available SRS resources are limited to a single SC-FDMA symbol per sub-frame. Thus, the increased SRS usage may easily lead to a channel sounding period being forced to be increased. This limits the useful velocity range for FDPS and (short-term) closed loop pre-coding. The increased SRS usage may lead to a level of inter-cell interference being increased for SRS in synchronized networks due to CDM that is non-orthogonal between cells. This degrades the accuracy of SRS based channel sounding. In other words, performance of SRS based channel sounding may be a limiting bottleneck for widespread UL SU-MIMO or COMP usage.

[0023] The inter-cell interference challenge with DMRS based sounding refers to inter-cell interference due to non-orthogonal CDM between cells degrading the performance of detection in synchronized networks.

[0024] The pairing of DMRS-based sounding with normal DMRS is due to LTE/LTE-advanced DMRS properties: orthogonal DMRS multiplexing based on cyclic shifts requires alignment of corresponding PRB allocations. This means that DMRS-based sounding causes PUSCH scheduling limitations if DMRS-based sounding is semi-statically configured via higher layer RRC signalling. In LTE Rel-10, an orthogonal cover code was introduced to relax the same multiplexing limitation with MU-MIMO. If the other OCC is reserved for DMRS-based sounding, MU-MIMO scheduling flexibility is correspondingly reduced. A feasible option for DMRS-based sounding seems to be aperiodic sounding, where the sounding is PDCCH-triggered when one

of the few preconfigured sounding options fits to the DMRS resources left unused after PUSCH scheduling. Such an opportunity based operation reduces the benefits of DMRS based sounding to be rather marginal.

[0025] None of the earlier suggested solutions related to DMRS based sounding deal with inter-cell interference problem of DMRS based sounding. For example, a pilot scheme has been presented the one reference signal sequence to be used for both demodulation/detection and channel sounding. One pilot scheme for LTE uplink MIMO involves an antenna-specific solution in which orthogonal pilots are transmitted from multiple antennas respectively in TDM, CDM or FDM fashion. For example, with TDM fashion, the antenna-specific pilots are transmitted from different antennas in different sub-frames. The antenna-specific pilot is mainly used for beam selection. Another pilot scheme involves a beam-specific pilot in which only one pilot is transmitted by using the same beam as data transmission. Both antenna-specific and beam-specific pilots are transmitted in one UL sub-frame, by using some kind of multiplexing methods. A configurable RS strategy has also been presented, where non-pre-coded DMRS used to support PMI selection at eNB, is dynamically selected instead of pre-coded DMRS. This solution may be used to meet the SRS challenges related to SU-MIMO. Also a DMRS structure has been presented, which allows orthogonal DMRS multiplexing without any limitations on PRB allocation. This does not take sounding into consideration, but it allows DMRS multiplexing with arbitrary PRB allocations, and meets the challenge regarding the orthogonal multiplexing between sounding-DMRS and "normal" DMRS. Hence, it makes DMRS-based sounding an attractive solution for future LTE releases.

[0026] Referring to FIG. 1, item a) of FIG. 1 illustrates a sub-frame structure with a normal cyclic prefix length when using an existing DMRS/SRS arrangement. Items (b), (c), (d) of FIG. 1 illustrate a sub-frame structure when using a DMRS/SRS arrangement according to an exemplary embodiment. An exemplary embodiment involves code division multiplexing (CDM) between SRS and DMRS, which minimizes overhead of SRS in the terms of inter-cell interference and frequency-time resources used for sounding. In order to minimize overhead, an exemplary embodiment allows transmitting DMRS and SRS in the same time domain resource as shown in FIG. 1. In an exemplary embodiment, UE uses one reference signal sequence for both demodulation/detection of data channel and channel sounding such that the sequence part used for demodulation/detection is in a power offset compared to the sequence part used for channel sounding. The lowered power on the SRS part results in significantly lowered inter-cell interference but still allows a sufficient quality for FDPS and pre-coder selection. The sufficient power of the DMRS part ensures a channel estimation quality that is sufficient for demodulation and detection. In an exemplary embodiment, CDM is applied on a reference signal sequence by means of a cyclic shift of a whole length of the sequence. The cyclic shifts may be selected such that the sequences allocated to different UEs are orthogonal over a minimum allocation granularity of a data channel. An orthogonal cover code may be applied over reference signal sequences. Orthogonal resources may be allocated to adjacent cells or COMP clusters in order to alleviate inter-cell interference. In an exemplary embodiment, UL sounding may be based solely on a proposed combination of SRS and DMRS as shown in item b) of FIG. 1, where one or more